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# Picosecond laser filamentation in air

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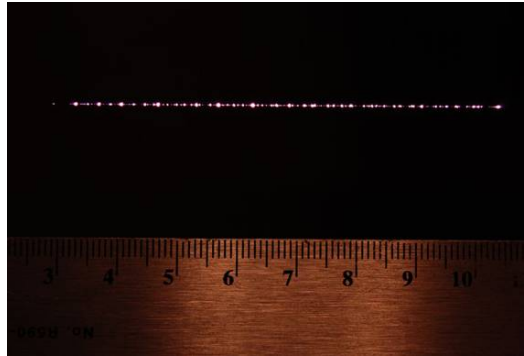
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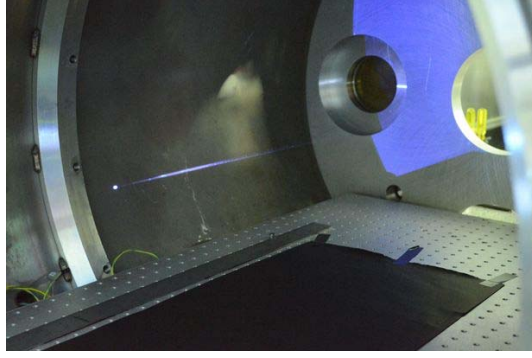
Laser-generated plasmas in air have potential utility in diverse application areas ranging from the guidance of electrical discharges to remote sensing. Ionization of air and other gases by powerful laser pulses has been intensely investigated in the femtosecond [1,2] and nanosecond [3] regimes. However, plasma channels produced through fs excitation are dilute and short-lived, while plasmas generated through nanosecond optical breakdown are typically fragmented into disconnected plasma bubbles. Both shortcomings severely limit practical applications. Attempts to combine femtosecond and nanosecond laser excitations in the so-called igniter-heater scheme [4] do result in the production of extended and dense plasma channels, but, like in the case of pure nanosecond excitation, the generated plasma channels are fragmented into discrete bubbles, as shown in Figure 1. The fragmentation effect is attributed to the periodic focusing of the nanosecond heater pulse by the rotational revivals impulsively initiated by the femtosecond igniter pulse.



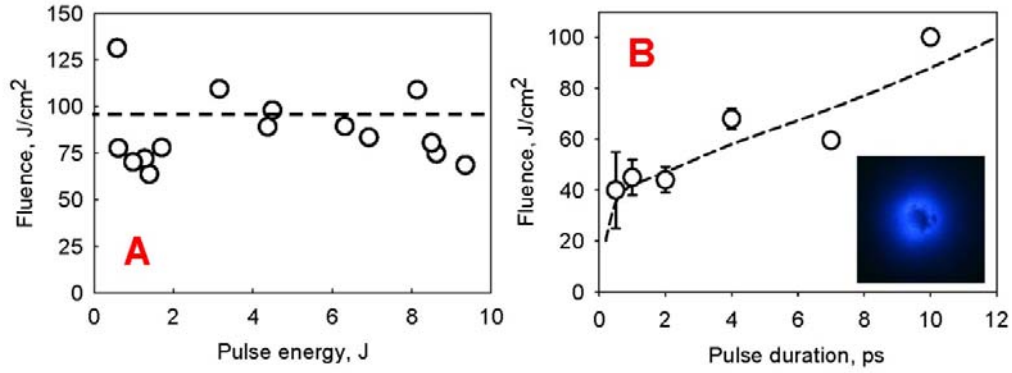
**Figure 1:** Photograph of a plasma channel produced in air through the combined femtosecond-nanosecond laser excitation (igniter-heater scheme). The channel is dense but fragmented into individual plasma bubbles.

In this contribution, we explore, both experimentally and numerically, an under-investigated regime of air ionization by intense near-infrared laser pulses with duration in the picosecond range. Earlier experiments have shown that in this regime the generated plasma channels can be both dense and continuous [5]. Here we use weakly focused laser pulses at 1,053 nm wavelength, with pulse durations variable from 0.5 to 10 picoseconds, and with the laser-pulse energies of up to 10 Joules. Plasma channels generated in air by such pulses are approximately uniform, both longitudinally and transversely, as shown on the single-shot photograph of plasma luminescence in Figure 2.

By examining burn patterns produced on a glass surface by the intense laser beam in the filamentation zone we show that the phenomenon of intensity clamping that has been originally demonstrated for the case of femtosecond laser filaments [6], holds in the picosecond regime. The value of the fluence steadily grows as the pulse duration increases, as shown in Fig. 3(B).



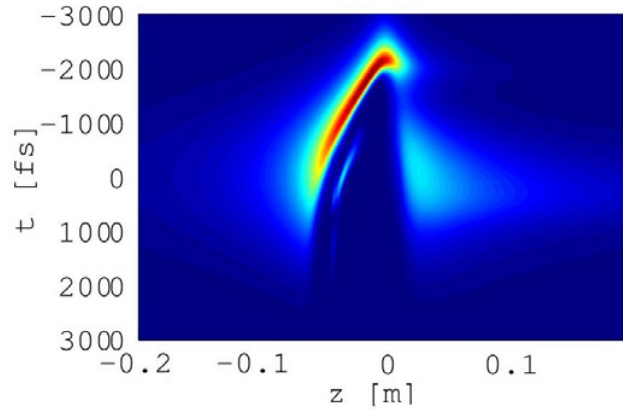
**Figure 2:** Photograph of a plasma channel produced in air through filamentation of a 10 Joule picosecond laser pulse at 1053 nm wavelength. The channel is both dense and continuous.



**Figure 3 A:** Optical fluence inside the filament produced by a 10 picosecond-long laser pulse, vs. input pulse energy. The fluence is  $\sim 100 \text{ J/cm}^2$  for all pulse energies, a direct consequence of intensity clamping inside the filament. **B:** Fluence vs. pulse duration. The inset shows the far-field fluence distribution. The shadow pattern is consistent with the screening of the laser beam by thick and dense plasma channel in the middle of the beam surrounded by several smaller plasma filaments.

Numerical simulations reveal that an intense, clamped spike develops on propagation, on the leading temporal edge of the pulse. Full ionization of both oxygen and nitrogen is reached, thus plasma densities attainable with energetic picosecond excitation are significantly higher than those in femtosecond laser filaments, which is a direct consequence of the longer pulse durations. Our results suggest that picosecond laser filamentation in air may have the advantages of both femtosecond and nanosecond plasma excitations, without the drawbacks associated with either of the two regimes.

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**Figure 4:** Simulation of the on-axis temporal evolution of a 2 ps-long laser pulse propagating through the filamentation zone, showing the development of an intense, clamped spike ( $\sim 80 \text{ TW/cm}^2$ ) on the leading edge of the pulse.

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